

Masses and semileptonic decays of doubly heavy baryons in a nonrelativistic quark model

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Abstract

We evaluate masses and semileptonic decay widths for the ground state of doubly heavy Ξ and Ω baryons in the framework of a nonrelativistic quark model. We solve the three-body problem by means of a variational ansatz made possible by heavy-quark spin symmetry constraints. Our masses are comparable to the ones obtained in relativistic calculations and we get one of the best agreements with lattice data. Our simple wave functions are used to evaluate semileptonic decays of doubly heavy Ξ , $\Xi'(J = 1/2)$ and Ω , $\Omega'(J = 1/2)$ baryons. Our results for the decay widths are in reasonable agreement with calculations done in a relativistic calculation in the quark-diquark approximation. We also check that our wave functions comply with what it is expected in the infinite heavy quark mass limit.

Key words: Nonrelativistic quark model, Hadron mass models, semileptonic decays, charmed and bottom baryons

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1. Introduction

In this contribution we present results for masses and semileptonic decay widths of doubly heavy Ξ and Ω baryons. The calculation has been done within a nonrelativistic quark model approach. In hadrons with two heavy quarks, heavy quark symmetry manifest itself as a spin symmetry amounting to the decoupling of the heavy quark spins in the infinite heavy quark mass limit [1]. In that limit one can consider the total spin of the two heavy quark subsystem to be well defined. In this work we shall assume this is a good approximation for the actual heavy quark masses that we use. This approximation simplifies the solution of the baryon three-quark problem allowing for a simple variational ansatz for the orbital wave function. This approach leads to simple and manageable wave

functions and it was already applied, with obvious changes, in the study of baryons with one heavy quark [2]. In order to estimate part of the theoretical uncertainties affecting our calculation we have considered several simple phenomenological quark–quark interactions taken from Refs. [3,4,5]. Their free parameters have been adjusted in the meson sector and are thus free of three–body ambiguities. Due to lack of space we shall concentrate in what follows in showing part of our results. Interested readers can find all details of the calculation and further results in Ref. [6].

2. Some results

In Table 1 we show the masses of doubly cc and bb baryons that have also been evaluated in lattice QCD [8,9,10], and the one experimental result for $M_{\Xi_{cc}}$ by the SELEX Collaboration [7]. Our central results have been obtained with the AL1 potential of Refs. [4,5], while the errors shown account for the spread in the results stemming from the use of different interquark interactions. For doubly c baryons we get good agreement with lattice data whereas for doubly b baryons our masses are a 100 MeV lower. The only experimental result has not been confirmed by other Collaborations and has at present a one-star status. Lattice simulations can also produce independent determination of mass

	This work	Exp.* [7]	Latt. [8]	Latt. [9]	Latt. [10]
$M_{\Xi_{cc}}$	3612^{+17}_{-17}	3519 ± 1		3605 ± 23	3549 ± 95
$M_{\Xi_{cc}^*}$	3706^{+23}_{-23}			3685 ± 23	3641 ± 97
$M_{\Xi_{bb}}$	10197^{+10}_{-17}		10314 ± 47		
$M_{\Xi_{bb}^*}$	10236^{+9}_{-17}		10333 ± 55		
$M_{\Omega_{cc}}$	3702^{+41}_{-41}			$3733 \pm 9^{+7}_{-38}$	3663 ± 97
$M_{\Omega_{cc}^*}$	3783^{+22}_{-22}			$3801 \pm 9^{+3}_{-34}$	3734 ± 98
$M_{\Omega_{bb}}$	10260^{+14}_{-34}		$10365 \pm 40^{+11}_{-12}{}^{+16}_{-0}$		
$M_{\Omega_{bb}^*}$	10297^{+5}_{-28}		$10383 \pm 39^{+8}_{-8}{}^{+12}_{-0}$		
$M_{\Xi_{cc}^*} - M_{\Xi_{cc}}$	94^{+5}_{-11}			80 ± 11	87 ± 19
$M_{\Xi_{bb}^*} - M_{\Xi_{bb}}$	39^{+1}_{-6}		20 ± 6		
$M_{\Omega_{cc}^*} - M_{\Omega_{cc}}$	81^{+11}_{-19}			68 ± 7	67 ± 16
$M_{\Omega_{bb}^*} - M_{\Omega_{bb}}$	37^{+6}_{-9}			20 ± 5	

Table 1

Baryon masses and mass differences obtained in this calculation as compared with lattice data.

differences. Our mass differences are always larger. The best agreement is reached for the potential in Ref. [3] for which we get always the lowest results. Mass and mass differences comparisons with other models (different versions of the relativistic quark model, and lattice nonrelativistic QCD) can be found in Ref [6].

With our simple wave functions we have further evaluated form factors, differential decay widths and integrated decay widths for $b \rightarrow c$ driven semileptonic transitions between doubly heavy baryons with total spin $J = 1/2$. In Table 2 we show our results for the decay widths. We compare them with the results by Ebert *et al.* [12] evaluated in a relativistic quark model in the quark diquark approximation and with the results

	This work	[12] RTQM	[13] HQET
$\Gamma(\Xi_{bb} \rightarrow \Xi_{bc} l \bar{\nu}_l)$	$3.84^{+0.49}_{-0.10}$	3.26	28.5
$\Gamma(\Xi_{bc} \rightarrow \Xi_{cc} l \bar{\nu}_l)$	$5.13^{+0.51}_{-0.05}$	4.59	0.79 8.93 4.0
$\Gamma(\Xi'_{bb} \rightarrow \Xi'_{bc} l \bar{\nu}_l)$	$2.12^{+0.26}_{-0.05}$	1.64	4.28
$\Gamma(\Xi'_{bc} \rightarrow \Xi_{cc} l \bar{\nu}_l)$	$2.71^{+0.19}_{-0.05}$	1.76	7.76
$\Gamma(\Omega_{bb} \rightarrow \Omega_{bc} l \bar{\nu}_l)$	$4.28^{+0.39}_{-0.03}$	3.40	28.8
$\Gamma(\Omega_{bc} \rightarrow \Omega_{cc} l \bar{\nu}_l)$	$5.17^{+0.39}$	4.95	
$\Gamma(\Omega_{bb} \rightarrow \Omega'_{bc} l \bar{\nu}_l)$	$2.32^{+0.26}$	1.66	
$\Gamma(\Omega'_{bc} \rightarrow \Omega_{cc} l \bar{\nu}_l)$	$2.71^{+0.17}$	1.90	

Table 2

Semileptonic decay widths in units of 10^{-14} GeV. We have used a value $|V_{cb}| = 0.0413$. l stands for a light charged lepton, $l = e, \mu$

by Guo *et al.* [13] obtained with the use of the Bethe-Salpeter equation applied to a quark-diquark system. We find a reasonable agreement with the calculation by Ebert *et al.* while the results in the Bethe-Salpeter approach of Guo *et al.* are much larger.

Finally comment that we have also checked that our variational wave functions have the correct infinite heavy quark mass limit. In that limit the wave function should look like the one for a meson composed of a light quark and a heavy pointlike diquark. In our model the pointlike nature of the heavy diquark comes about through the one-gluon exchange Coulomb potential, present in the interquark interactions we use, that binds the two heavy quark into a distance given by the inverse of their reduced mass. Besides we have shown that as the heavy quark mass increases our wave function reduces to the product of the ground state wave function for the heavy diquark subsystem times the ground state wave function for the relative motion of the light quark with respect to the center of mass of the heavy diquark.

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